Floor vibrations due to walking loads

FLOOR VIBRATIONS DUE TO WALKING LOADS

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Abstract:

Traditionally floors are designed for static strength and stiffness. Improved methods of construction and design, using high strength-lightweight materials, have resulted in strong and stiff floors that display unsatisfactory dynamic behaviour when exposed to walking loads. The paper discusses a method, partly based on recent work at Eindhoven University of Technology, to predict the dynamic response of floors subjected to walking forces. Several floor types were tested and analysed by this method. The results of these tests are presented and compared to floor vibration criteria that are based on ISO 2631.

1 INTRODUCTION

Traditionally, floors are designed for static strength and stiffness. The stiffness criteria have also acted as a kind of a guarantee that excessive vibrations due to dynamic loads will not occur. Improved methods of construction and design, using high strength-lightweight materials, make that these criteria do no longer perform this function satisfactorily. Subsequently, the dynamic behaviour has become an increasingly important part of floor design.

Floor vibrations can be induced by both external forces, such as road and rail traffic, and by internal forces such as rotating machinery. Probably the most important cause of these vibrations in residences and offices, however, is pedestrian traffic. These floor motions can cause annoyance, which makes it difficult to concentrate, or even sickness.

This paper deals with a method for predicting the dynamic response of floors subjected to walking forces. Several floor types were analysed by this method. The results of these tests are presented and compared to floor vibration criteria that are based on ISO 2631.

2 FLOOR VIBRATION CRITERIA

ISO standard 2631 contains an average vibration perception threshold, which may be considered as a base curve for floor vibration criteria. A criterion is found when the perception threshold is multiplied by a constant, the so-called multiplication factor. ISO 2631 suggests values for the multiplication factor as function of the floor use and the type of vibration imposed on the floor.

This paper considers floor vibrations induced by walking, whose character is a mix of transient and continuous components. It is therefore proposed that multiplication factors are used for floor vibrations due to walking that are slightly higher than the values suggested by ISO 2631 for continuous loads. Accordingly, Wyatt and Dier [4] proposed multiplication factors of 4 and 8 for residential and office floors respectively. The corresponding criteria are shown in figure 1.

The two criteria in figure 1 were used to compare the different floor types that were tested in this project.

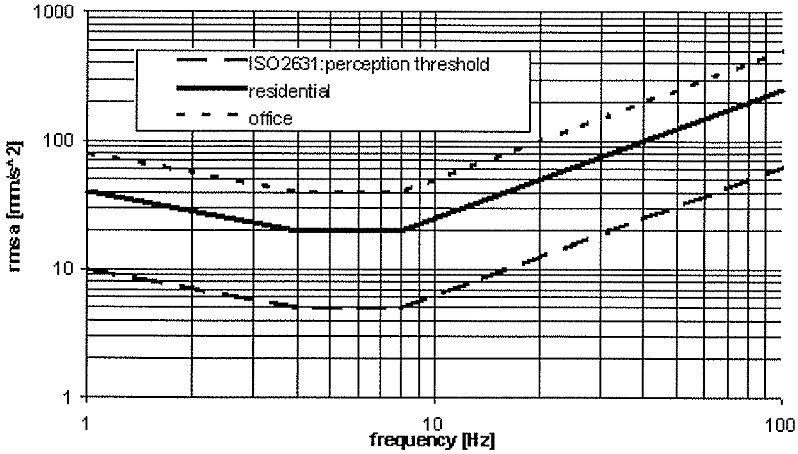

Fig. 1 Annoyance threshold for vertical floor vibrations according to ISO standard 2631 [3].

3 DYNAMIC BEHAVIOUR IDENTIFICATION

The dynamic properties of the floors are obtained through experimental modal analysis (EMA). The technique of EMA, where a controlled force excites a structure and the resulting vibrations are measured simultaneously, is discussed by Ewins [2].

In this study the dynamic properties of a floor were identified by a mass drop test. In this test a sand-filled ball of about 3 kg is dropped from a height of 1 m. The ball hits the floor at mid-span. The force spectrum due to the impact of the ball is relatively flat, i.e. all major frequencies are excited by this impact.

The response of the floor has been measured at mid-span, 600 mm to the left and the right of the impact. A typical time trace of the floor acceleration is shown in figure 2a. The corresponding transfer function (force to acceleration) is found when the response spectrum is divided by the force spectrum. A typical floor transfer function is shown in figure 2b.

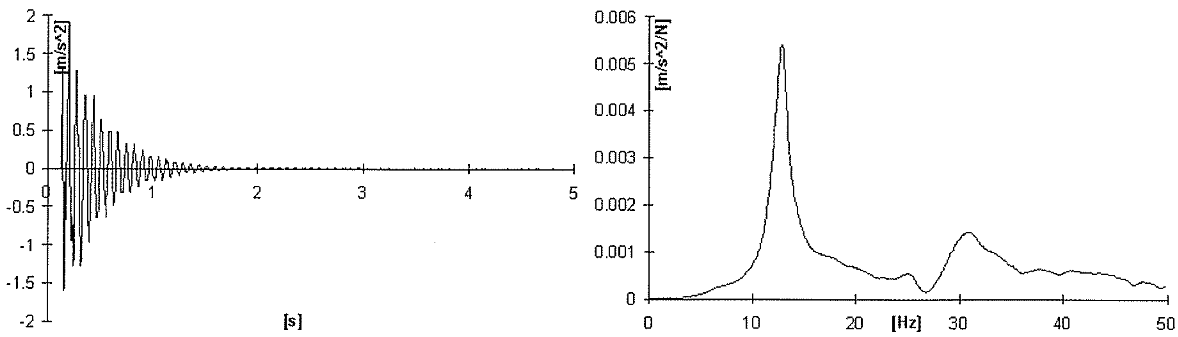

Fig.2 a) Response time history b) Transfer function

The transfer function of a floor may be used to assess modal parameters. For example, figure 3b clearly shows a lowest natural frequency of 13 Hz. Modal damping may be determined from the transfer function by means of the half power bandwith method.

4 DYNAMIC FORCES DUE TO WALKING

4	concrete/steel	wood	6.0	47	-
5	concrete	wood	4.8	23	4.8

The response of the investigated floors due to walking can now be predicted since both the relationship between force and response, which is enclosed in the floor transfer function, and the dynamic forces due to walking have been established.

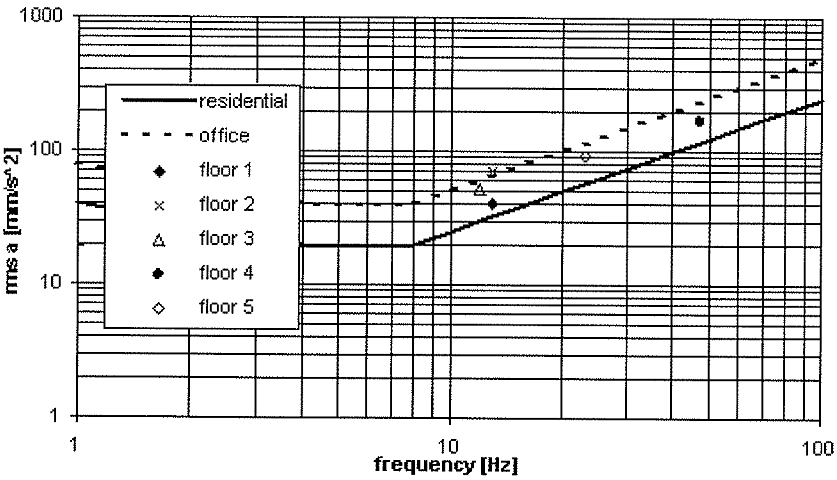

Fig. 4 Predicted floor response due to walking plotted against the criteria according to ISO Standard 2631.

The root mean square values of the predicted vibrations have been checked against the criteria that were established in section 2. Figure 4 shows the performance of the five floor types. Floor types 1, 3, 4 and 5 meet the office criterion. The performance of floor 2 is poor, in spite of the high value of the modal damping, as none of the criteria is met.

Improving the dynamic behaviour of floor 2 by increasing the floor modal damping therefore is not an option. Improvement may be achieved by increasing the floor stiffness, for instance by reducing the span of the floor.

6. CONCLUSIONS

In this paper a method for predicting the dynamic response of floors subjected to walking forces is presented. Both the dynamic forces due to walking and transfer functions of different floors have been established experimentally. Walking forces can be considerd as a mixture of low frequency continuous and high frequency impulsive components.

All concrete and concrete composite floors meet the office criterion. The performance of the steel IBS-floor is questionable since only one variant meets the office criterion. Improvement of the dynamic behaviour however may be realized by increasing the floor's stiffness.

References

[1] Donkervoort D.R.: Floor Vibrations - Prediction of the dynamic behaviour due to walking loads (in Dutch), TUE CO 98.13, Eindhoven, May 1998.

[2] Ewins D.J.: Modal Testing – Theory and Practice, Research Studies Press Ltd, Letchworth, England, 1986.

Once the transfer function between force and response has been established, forces due to walking can be easily assesed by walking on top of the floor and measuring the resulting vibrations. Figure 3a shows a typical floor response due to walking.

The floor response spectrum, in combination with the transfer function, yields the floor walking load spectrum, as is shown in figure 3b.

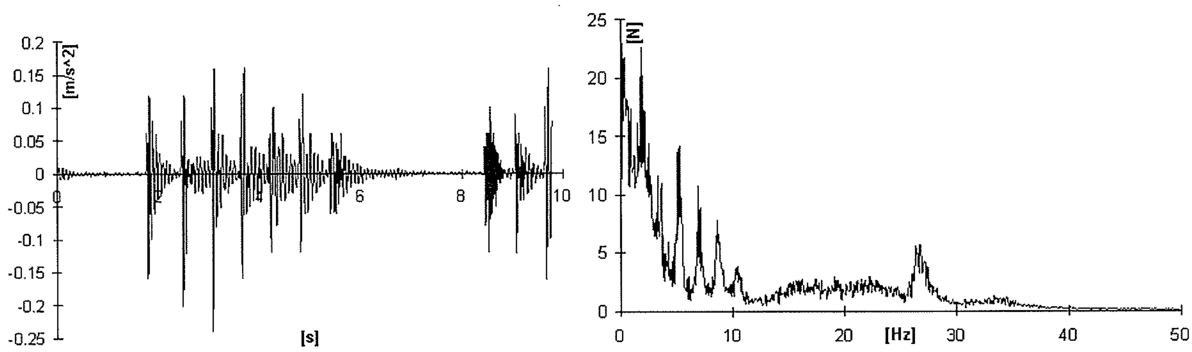

Fig. 3 a) Floor response due to walking b) Walking force spectrum.

Walking causes a combination of impulsive (from the initial contact between the floor and the foot) and continuous (from the successive footsteps) forces. The main components of the continuous forces are below 8-10 Hz and may be recognized in figure 3b by the peaks at 2, 4, 6, 8 and 10 Hz, representing the stepfrequency and its higher harmonics. The impulsive components of the walking loads mainly contribute to the force spectrum above 15 Hz, as can be appreciated from components above 8-10 Hz.

5 PREDICTION OF FLOOR VIBRATIONS DUE TO WALKING

Six different floor types were tested in this study. Floor type 1 is a precast concrete ribbed floor element.

Floor types 2 and 3, known as the IBS-floor (Innovative Building System), are constructed out of thin trapezoidal shaped steel plates. Both floors are topped with hardboard, insulation material and plasterboard and only differ as far as the finishing layer is concerned.

A 50-mm concrete slab with integrated vertical ribs is the basic concept for both floor types 4 and 5. The floors, topped with plywood, differ in the rib concept that was used. In floor type 4 the ribs were made of steel I-beams, where in floor type 5 the ribs consisted of conrete beams. Table 1 summarizes the modal parameters of the investigated floors.

Table 1 Modal parameters of the investigated floors

floor no.	material structural parts	material top layer	span (m)	resonance frequency (Hz)	damping (%)
1	concrete	concrete	5.6	13	3.3
2	steel	wood / tiles	5.4	13	10.5
3	steel	wood / carpet	5.4	12	13.9

[3] International Standard 2631 Part 2, Guide for the Evaluation of Human Sensitivity to Whole Body Vibrations, International Organization for Standardization, 1974.

[4] Wyatt T.A. & Dier A.F.: Floor Serviceability under Dynamic Loading, CIB W 85 paper no.20.